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Abstract

REACTOR PHYSICS IN THE THERMAL ENERGY REGION

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The physical description of the thermalization and transport of neutrons below a few electron volts is very important in advanced thermal-reactor design. This description expressed in terms of low-energy scattering cross sections may be combined with the necessary fission, absorption, and fast transport cross-section data for calculation of reactor neutron spectra and performance. The many special numerical methods now available for accomplishing this task permit relatively great refinement to be incorporated in the parametric reactor design calculations providing the basic cross-section data are known. However, only in recent years has the treatment of low-energy neutron-scattering cross sections (thermalization) been considered in other than an elementary manner because of the complications introduced by moderator lattice structure and chemical binding.

Extensive work has been carried out in the U.S. to develop scattering kernels of the required accuracy for the common reactor moderators H_2O, D_2O, $(CH_2)_n$, C_6H_6, C, Be and ZrH_x. The procedure used has been to relate the theoretical scattering model to known physical and chemical properties of the moderator; i.e., temperature dependence of the specific heat, vibrational. and rotational frequency spectra, elastic constants, dispersion relations, total neutron cross sections, etc. Another procedure has been to use experimentally determined $S(\alpha,\beta)$ to derive a phonon frequency distribution. Use of $S(\alpha,\beta)$ directly in reactor calculations has been impractical because experimental data are not available over the entire range of variables α, β and temperature.

The adequacy and limitations of the theoretical scattering kernels have been studied experimentally for the above moderators by measurements of steady-state spectra, spatial flux distributions and time-dependent behavior under experimental conditions applicable to reactor analysis. Verification of the theoretical scattering kernels from the standpoint of the reactor analyst represents a fairly extensive undertaking since thermal spectra and other reactor parameters must be measured for theoretical comparisons over a wide range of temperature ($\lesssim$ 60K to $\gtrsim$ 1000K), absorption, and spatial fluxes. An investigation of neutron spectra in clean geometries approaching those of an infinite medium constitutes one of the simplest and most appropriate tests of thermal scattering kernels. These studies have been extensively carried out in the U.S. at ambient temperatures for the common reactor moderators. It has been shown that the scattering kernels based on a knowledge of the molecular or crystalline structure of the above moderators permit the reactor analyst to predict neutron spectra with far more precision than possible with the previous free-atom scattering descriptions or various arbitrary prescriptions. Many temperature-dependent spectral experiments have been carried out, and, again, the more realistic scattering descriptions are beginning to provide the accuracy required for present reactor analysis. In addition, these measurements, which essentially establish the validity of the inelastic isotropic component of the scattering kernel, serve as the basis for further model refinements and adjustments in the scattering models.

Angular flux spectra (spectra in finite media) have been especially difficult experimentally to study unambiguously. These measurements provide an important test of both the isotropic and the anisotropic components of the scattering kernel. Experimental results indicate some significant discrepancies in the theory under boundary conditions similar to those in actual reactor lattices. Other experimental investigations which serve to test thermal scattering kernels from the standpoint of reactor design are measurements of thermal diffusion length by pulsed or continuous absorption techniques, thermal flux distributions at spatial and temperature discontinuities, and time-dependent spectral studies.

Generally applicable numerical techniques for the calculation of thermal scattering kernels are being developed in the U. S. and tested by the above experimental procedures These flexible methods are planned to incorporate many special provisions required by users; for example, the choice of moderator, energy mesh, moderator temperature, and crystalline structure.